Pilot Studies In Tagging Prince William Sound Hatchery Pink Salmon With Coded-Wire Tags

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FOREWORD

The two studies described in this report represent two of the most successful endeavors involving tagging or marking juvenile salmon that the Alaska Department of Fish and Game has ever undertaken. This is in spite of the fact that the species tagged were pink salmon (*Oncorhynchus gorbuscha*). This nonsmolting species must be tagged at emergence, when the fry are considerably less than half a gram. Because of the extremely large numbers of pink salmon produced in the Prince William Sound hatcheries, each tagged fish must represent hundreds of untagged fish.

The reasons for the successes in these studies are attributed to the organization and cooperation of the participants. Before any tagging was done, the technical aspects of these studies had been thoroughly discussed by all parties. Subsequently, the tagging, recovery, and analysis was closely coordinated. The hatchery operators devoted substantial resources to tagging and permitted disruptions of their hatchery operations for the purpose of data collection. The Alaska Department of Fish and Game, Fisheries Rehabilitation, Enhancement and Development Division, provided excellent planning and organization for the 1987 study and organized and summarized the initial data from this study. This initial planning and written descriptions of tagging standards and protocols will form the basis for all future coded-wire tagging studies in Prince William Sound and will hopefully be transplanted to other areas of the state. The Alaska Department of Fish and Game, Commercial Fisheries Division in 1988 assumed the task of sampling, data collection, and organizing and summarizing the data.

There have been failures in Alaska to bring coded-wire tagging studies of nonsmolting species to useful conclusions. This has resulted in questioning the coded-wire tag method for pink and chum salmon. These Prince William Sound studies have shown that the coded-wire tag technique works. The technique works even with tagging rates in the parts per thousands, provided sufficient care is taken to test the basic statistical assumptions that underlie the method and the flexibility to make the statistical methods fit actual situation. The first lesson from the Prince William Sound experience is that the planning, tagging, sampling, and summarization can not be done separately. There must be close cooperation and planning between the fish culturists, the sampling and data collection group, and the party charged with summarizing and forming conclusions from the study. The second lession is that sufficient recources must be devoted to the project, and there must be a commitment by all parties to modify their usual operation in order to gather the necessary information and to identify and respond to problems. The final lesson for other hatchery operators planning coded-wire tagging studies is that the first step in a successful study is to develop a clear understanding and agreement of who is responsible for each aspect of the study, especially who will develop the written conclusions.

A Tagging Study Of The Effects Of Hatcheries On The 1987 Pink Salmon Fishery In Prince William Sound, Alaska

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ABSTRACT

Commercial harvests of pink salmon (*Oncorhynchus gorbuscha*) have occurred since 1896 in Prince William Sound, Alaska. In 1975 an aggressive hatchery building program was begun, and by 1987 the hatcheries in Prince William Sound reached a combined capacity of over 600 million pink salmon eggs. In 1986, as a possible aid to the management of this complex fishery, a tagging study was undertaken to test the feasibility of using half-length, coded-wire tags to estimate the hatchery component of the commercial pink salmon harvest from various areas in Prince William Sound. In 1987 tags were recovered, and an estimated 13.7 million pink salmon, or slightly over half of the 1987 commercial catch in Prince William Sound, were fish of hatchery origin. This represented approximately $18 million in ex-vessel value to fishermen. In the future the hatchery component of the catch is expected to rise to 30 million fish. The half-length, coded-wire tagging technique was judged to be a workable tool for estimating hatchery pink salmon contributions in Prince William Sound Fisheries, and its use in the management of these fisheries is recommended.

INTRODUCTION

The Prince William Sound (PWS) area of southcentral Alaska has supported a commercial seine harvest of pink salmon (*Oncorhynchus gorbuscha*) since 1896. Over 900 anadromous streams in PWS support pink salmon populations. There are eight fishing districts in PWS (Figure 1). The vast majority of the pink salmon harvest occurs in the seven purse seine districts. All purse seine harvests are from mixed stocks, and in recent years over 50% of the catch has occurred in the Southwestern District. The Southwestern District catch includes a mixture of wild stocks destined for the western and northern portions of PWS as well as hatchery stocks from three of the four PWS hatcheries.

During the period 1910-70, harvests ranged from a high of over 12 million in 1945 to less than 1 thousand in 1959. A dramatic decline in salmon stocks occurred in PWS and statewide in the early 1970's. In response to this decline, the state of Alaska embarked on an aggressive enhancement program. An integral segment of the enhancement program was the construction of numerous hatcheries, some of which were owned and operated by the state of Alaska. Other hatcheries were built and operated by private nonprofit (PNP) corporations with loans secured through the state. Two classes of PNP corporations were established: one class was owned and controlled by regional fishermen's associations, and another was open to nonassociation PNP corporations. By law, both classes of PNP hatcheries were allowed to sell fish returning to the hatchery to support their operations. In addition, the regional association PNP hatcheries were also funded through a tax on commercial fish catches.

The first PNP hatchery began operation in 1975 in PWS with an egg take of 8 million pink salmon eggs. By 1986 PWS had three PNP hatcheries and one hatchery operated by the state. At that time the combined pink salmon egg capacity was over 600 million eggs. Pink salmon catches have increased greatly through the 1980's. The 1979-85 mean catch of wild and hatchery stocks was 18.8 million fish. The majority of the pink salmon production during this period was from wild stocks. Hatchery production gradually increased as the individual hatcheries were constructed and the brood stock developed. In 1989 hatchery production was expected to be near 27.5 million fish. This level of hatchery production will overshadow all except historically high wild stock production levels.

Management of this complex mixed stock fishery is extremely difficult, and even more difficult without the ability to differentiate between wild and hatchery stocks. If managers are to provide adequate wild stock escapements to natal streams, and sufficient hatchery escapements for brood stock and cost recovery, segregated harvest opportunities and differentiation between hatchery and wild stocks will be necessary. Otherwise, managers may err because of the lack of understanding of temporal and spacial distribution of the different stocks. If hatchery stocks are overharvested, the economics of the hatchery would be seriously affected, and the hatchery would have difficulty being economically self-sustaining. Alternatively, managers could mistake hatchery production for wild production, resulting in the overharvest of wild stocks, and wild stocks would have difficulty being biologically self-sustaining. For both reasons a tool is needed to allow management to identify the presence of hatchery stocks in mixed stock fisheries.

Ricker (1975) discussed the danger to less productive stocks in a mixed stock fishery and specifically explains how enhancement places wild stocks at risk. Hatchery stocks of salmon are more productive than wild stocks because survival in the early life stages is much higher in hatcheries. When wild stocks and hatchery stocks are harvested together in fisheries that have traditionally been managed based on observed abundance, managers may err. They may mistake large hatchery stocks for wild stocks which are actually in low abundance. This will result in wild stock overharvest. Once the wild stocks become depressed, the fishing industry will be reluctant to forego hatchery harvest to rebuild the wild stocks. Loss of wild stock production may have occurred at various times and places in the past because of unattentive fisheries management, but it is difficult to detect. Walters and Cahoon (1984) offer evidence that less productive wild coho runs in British Columbia have been depleted by the mechanism that Ricker describes, although the effects of habitat destruction are hard, if not impossible, to distinguish.

In 1986 the Alaska Department of Fish and Game (ADF&G) initiated a research project to investigate the feasibility of using half-length, coded-wire tags (HLCWT) to differentiate between wild and individual hatchery stocks of pink salmon. HLCWT have been successfully used on smaller-size fish (Opdycke and Zajac 1981; Thrower and Smoker 1984), but an HLCWT program has not been used to evaluate large-scale releases of pink salmon in the hundreds of millions. This study was designed to meet two goals.

The first goal was to evaluate the performance of the HLCWT. This has been previously discussed by Peltz and Miller (*In* *press*). They were specifically concerned with optimal rates of tag application subject to the following practical constraints: overnight and long-term tag retention, tag placement, changes in the tagged-to-untagged ratio between release and return, and numbers of tags recoverable from the commercial fishery. The second goal, which was our investigation, was to estimate hatchery contributions to the purse seine fishery in the Southwestern District, where most of the mixed stock fishery occurs. In this paper we examine estimates of the season total contribution from each hatchery to the Southwestern District fishery, estimates of individual hatchery contributions to other fishing districts, and methods for dealing with the shortcomings in the information.

METHODS

Tagging and Tag Recovery

HLCWT were applied at the Armin F. Koernig (AFK) Hatchery, Esther Hatchery (both owned and operated by the Prince William Sound Aquculture Corproration) and Cannery Creek Hatchery (at the time owned and operated by the State of Alaska) in the spring of 1986 (Figure 1). Over 200,000 tags with two tag codes (enabled fish to be identified by group code but not by individual) were applied at each hatchery. Each tagged fish was externally marked by the removal of the adipose fin. Tags and tagging equipment were purchased from Northwest Marine Technology. The tagging methods and quality control measures for this study have been previously described by Peltz and Miller (*in press*).

In July and August 1987 commercial catches of adult pink salmon were sampled for fish without adipose fins (marked fish) at the four largest processors of PWS pink salmon (three in Cordova and one in Seward). Processor, and in some cases sampler-specific information, was not released in this report because of confidentially requirements. At each processing plant one tag recovery person scanned as many fish as possible on the sorting line as the fish were pumped from tenders. The volume of fish on the sorting line was large; consequently the maximum number of fish a person could be reasonably expected to scan was approximately 35% of the total load of each tender. Each tag recovery person counted only the number of fish actually examined for marks from each tender. Fish were scanned one-by-one, and only fish with a clearly observed adipose fin or missing adipose fin were counted as part of the sample. When the adipose fin area of the fish was not clearly visible to the sampler, the fish was not counted as part of the sample, nor were marked fish otherwise brought to the samplers' attention counted as part of the sample. Marked fish not part of this sample were not processed. Samplers removed the marked fish from the sorting line, excised the heads, then stored the heads in a freezer for processing at a later time.

Brood stock returns at each hatchery were sampled for marked fish to determine the rate of mark occurrence at return. One person at each hatchery scanned the brood stock at the spawning rack to find marked pink salmon. The brood stock tag recovery goal at each facility was 200 valid tags. Based on anticipated returns, a required minimal percentage of the brood stock was scanned daily: 25% at Esther Hatchery and 50% at AFK Hatchery and Cannery Creek Hatchery. Heads from marked fish were excised and frozen for later processing. The number of fish in the brood stock, untagged but from the tagged cohort, was estimated by expand-

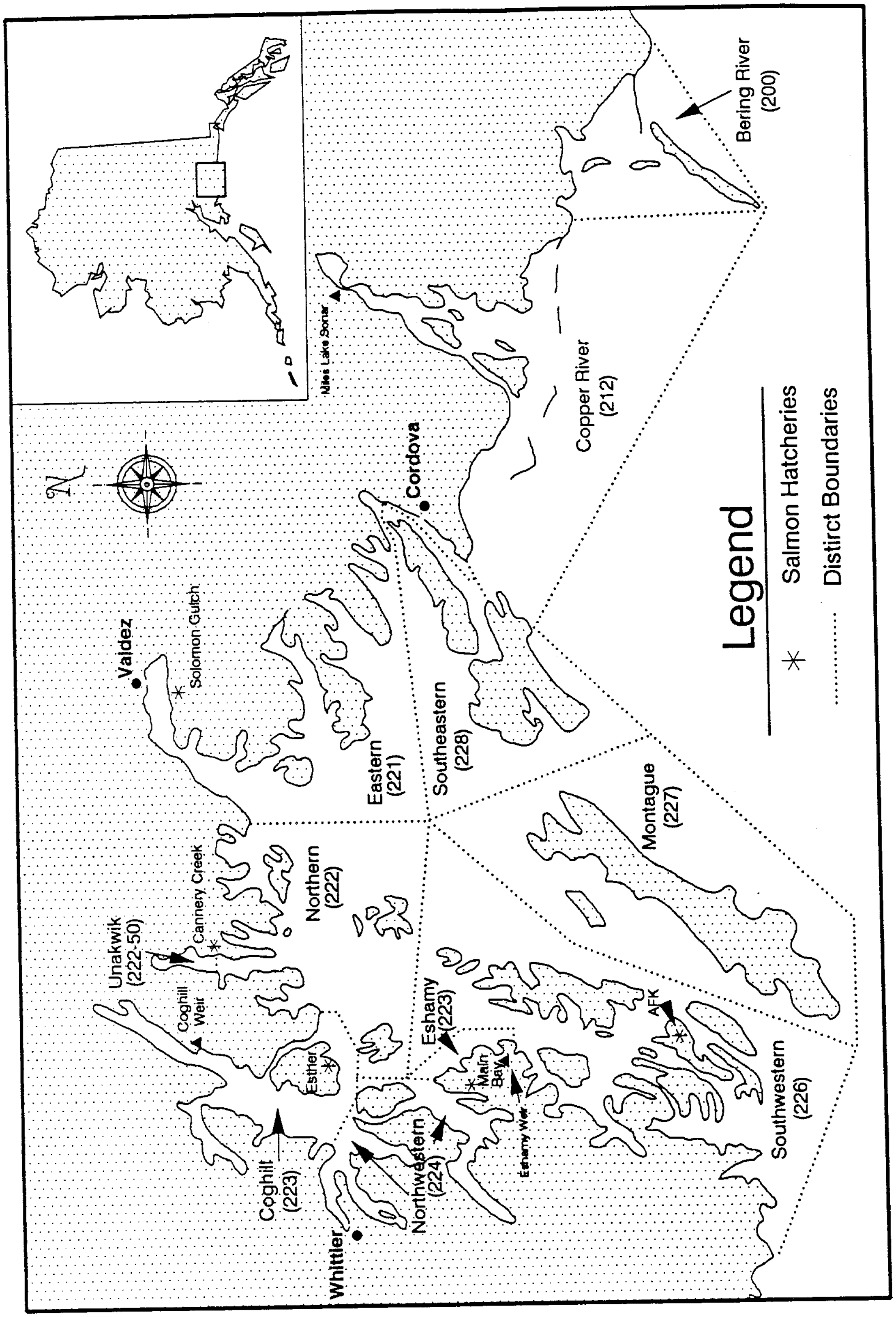

Figure 1. Map of Prince William Sound showing commercial fishing districts and hatchery locations.

ing observed tags by the inverse of the reported tag rate at release, then scaling the resultants to equal the number scanned.

Heads from marked fish in both commercial and brood stock recovery were sent to the ADF&G's Coded-Wire Tag Recovery Laboratory in Juneau for tag extraction, decoding and computer data entry.

The total commercial catch of pink salmon was determined from sales receipts (fish tickets), which by law document each catch sold by fishermen. Fish ticket data includes the size of the catch, the fishing district in which the fish were captured, the week the fishing occurred, and the processor that purchased the fish.

The Contribution Estimation Methods

The proportion of the release group tagged with tag code t (t=A...Z) is denoted as $P(t)$. Let N_i denote the number of fish caught in fishery i (i=1...k), let i denote the number of fish in that the fishery sampled for marks, and let $x_i(t)$ denote the number of tags recovered with code t in fishery$i$. The number of fish from the release group represented by tag code t that were caught in the commercial fishery, $C(t)$, is estimated as follows:

$$\hat{C}(t) = \sum_i x_i(t)\,(N_i/s_i)\,P(t)^{-1}\,. \qquad (1)$$

Clark and Bernard (1986) describe a theory for the estimation of confidence intervals for $C(t)$ using a large sample approximation to the Gaussian (normal) distribution. Using the method of moments, they recommend an estimator for the variance of the estimate of $C(t)$ including terms covariance for multiple tag codes. Using the approximation suggested by Geiger (*in press*) and ignoring negligible covariance terms, we used the following variance estimator:

$$\hat{v}(\hat{C}(t)) = \sum_i x_i(t)\,[(N_i/s_i)\,P(t)^{-1}]^2 \cdot \left\{1 - [\,(N_i/s_i)\cdot P(t)^{-1}]^{-1}\right\}. \qquad (2)$$

The assumptions necessary to estimate $C(t)$ and the associated confidence intervals are as follows:

1. the numbers of tagged and untagged fish are known exactly;
2. the tagged sample of the original hatchery release group is a simple random sample (i.e., every fish in the collection of fish under consideration has an equal probability of selection independent of every other fish in the sample);
3. the tags do not affect the fish with respect to the items under study (survival, timing, homing, etc.);
4. none of the marks are lost;
5. the number of fish in the fishery (or each recovery stratum) and the number of fish in the fishery sample are known exactly;
6. the sample of the fishery is a simple random sample; and
7. all marks are observed and all tags decoded.

RESULTS AND DISCUSSION

Diagnostic Checks on the Tag Rate

The tag rates at release were compared to the rates at adult return to checked for the possibility of tag loss and differential mortality of tagged and untagged fish during the at-sea period.

The AFK Hatchery

At the AFK Hatchery, the overall tag rate at release was reported to be 1.9 tagged fish per 1000 fish released. The group of fish used for brood stock was a sample from the overall escapement, which also includes fish for cost recovery harvest. The escapement was itself a sample from the entire return (both captured and uncaptured adults returning to spawn). The observed tag rate in the brood stock was 2.0 tags per 1000 fish observed. Latent tag loss and greater mortality of tagged fish were expected to result in a small drop in the tag rate from the time of tagging until the adults were recovered. This higher tag rate in the brood stock could mean that (1) a release group with a higher tag rate had better survival, (2) the hatchery managers overstated the actual size of the release, or (3) possibly the tag mortality or number of poor fin clips had been overstated.

Because one release group had a tag rate above 2.0 tags per 1000 at release, the first alternative cannot be ruled out entirely. It is also impossible to rule out inventory problems at this time. In reviewing the documentation of the tagging protocols, we concluded that the number of tagged fish had been underreported at the time of release because of a large "discounting factor" that had been applied to correct for poor fin clipping.

Tag code A had 1.2 tags recovered in the brood stock per 1000 tagged fish released from the hatchery, while tag code B had 0.3 tags recovered per 1000 tagged fish released from the hatchery. This produced a presumed difference in survival of 4 times. Alternatively, the fishery resulted in 4.5 tags per 1000 tagged fish released of tag code A versus 2.1 tags per 1000 tagged fish released of tag code B, a presumed difference in survival of about 2.1 times the survival of code A. Table 1 shows the actual counts of recovered tags in both the fishery and the brood stock. A statistically detectable association of the abundance of the tag code with mode of recovery (either brood stock or fishery) exists (X^2=4.46, df=1, P=.035). Notice there is a troubling dearth of tags of tag code B in the brood stock. This is suggestive of a differential representation of the two tag groups in the escapement and the harvest, i.e., that tag distribution was not similar in the escapement and harvests.

Table 1. Number of coded-wire tagged hatchery pink salmon recovered as adults in the brood stock and the 1987 Southeast District commercial fishery in PWS.

Hatchery/Source	Tag Recoveries[a]	
	First Code	Second Code
Esther Hatchery		
Brood Stock	311	58
Fishery	532	148
AFK Hatchery		
Brood Stock	189	14
Fishery	720	99
Cannery Creek Hatchery		
Brood Stock	51	89
Fishery	24	39

[a] Two tag codes were used at each hatchery to evaluate cultural practicies. The designation of first and second has no significance.

At the time of release, the expansion factors (inverse of mark rate) for the tags of code A and code B were 500 and 735, respectively. Because we observed an increase in the tag rate in the escapement, we used 479 and 705, respectively, in the analysis. These latter expansion factors are 4% lower than the original ones calculated at the time of release.

The Esther Hatchery

At the Esther Hatchery, the overall tag rate at release was reported to be 6.1 tags per 1000 fish released, while the observed tag rate in the brood stock was 5.3 per 1000 fish examined. This slight decline in tag rate is what was expected. Table 1 shows the actual counts of tags recovered in both the fishery and the brood stock. There was a detectable association of the tag code abundance in the fishery with the abundance in the brood stock (X^2=5.54, df=1, P=0.019). At the time of release, the reported expansion factors for tag codes C and D were 153 and 196, respectively. We used expansion factors that were 15% higher because of the observed lower tag rate in the brood stock. These revised expansion factors for codes C and D were 180 and 230, respectively.

The Cannery Creek Hatchery

At the Cannery Creek Hatchery, the overall tag rate was reported to be 4.0 per 1000 fish released, while in the brood stock the observed tag rate was substantially different at 1.8 per 1000 fish examined. Again, Table 1 shows the actual counts of tag recoveries in the fishery and the hatchery. There was no detectable association between the occurrence of tags of either code in the brood stock and the fishery (X^2=0.154, df=1, P=0.695). Either there was substantial mortality of tagged fish, substantial tag loss, or contamination of the brood stock by wild fish from nearby spawning areas, or all three.

Diagnostic Checks on the Samplers

The rates at which individual samplers were observing marks were compared to detect samplers that may have been overlooking marked fish in the sample. We plotted weekly mark recovery rates in the Southwestern District by individual sampler. By examining these plots, a substantial discrepancy in mark detection rates was discovered. One sampler appeared to be consistently detecting adipose marked fish at the rate of 1.5, or fewer, per 1000 fish examined. At the other extreme one sampler was detecting adipose marked fish at the rate of about 3 or 4 per 1000 fish examined. Other samplers were detecting marks at intermediate rates. A Kruskal-Wallis test across weeks showed a highly significant departure from a random pattern [P=8.0 (10^{-4})]. This indicated that either samplers differed in their ability to detect marked fish, or that the rates of marked fish differed among processors. Further analysis showed that the distribution of individual tag codes was different for different samplers. Clearly, the assumption that the fishery sample was a random sample of all fish in the fishery was incorrect.

We next attempted to lay out all the explanations for the differences in tag recovery rates; either (1) some samplers had done a substandard job, or (2) the different mark rate represented a fundamental difference in the proportion of hatchery fish processed at the different processors. Examination of the working location of the samplers revealed that the samplers tended to frequent the same processor or set of processors. It also appeared that tenders working for individual processors were buying fish from different parts of the Southwestern District and that they were buying fish with different stock compositions. Logs of tender location confirmed this was the case. The most convincing evidence that explanation (2) was in fact the dominant cause for differences in tag recovery rates was that the distribution of recoveries by tag code differed by processors (X^2=38.37, df=6, P = 0.005) when sampling fish from the same week and district.

The Preferred Analysis for the Southwest District

Although the diagnostic checks showed that within a week and within the Southwestern District the sample did not approximate a random sample, it still seemed reasonable to assume that for each processor the sampled fish constituted a random sample. So the processors needed to be incorporated into the structure of the sampling design.

The most reasonable way to proceed was to group the processors into like-groups based on where their tenders bought fish. Fortunately, detailed logs of the tender location were maintained by the sampling supervisor to help the port samplers schedule their work. For most of the unsampled processors, information about the distribution of the buyers was unavailable.

At the end of the season the sampled plants had processed 61.5% of the commercially harvested pink salmon in the Southwestern District, although it ranged from a high of 84% in the week of July 12-18 to a low of 0% in the week of September 6-12, when relatively few fish were processed. Floating processors, which were not sampled, were found to have processed 28.1% of the commercial catch in the Southwestern District. The floating processors and the sampled shore-based processors accounted for 89.6% of the harvest in the Southwestern District, and with the exception of the week of September 6-12, their combined weekly total fish processed did not fall below 86.8%.

Examination of the processor logs, in addition to conversations with fishery management personnel that had traveled around the Southwestern District during the season, revealed that the floating processors and the tenders for *Processor A* were both stationed in similar locations near the AFK Hatchery. The floating processors and the *Processor A* could then possibly be pooled into a single processor strata for the purpose of the analysis. This still left the group of processors that had not been sampled. This group processed only 5.5% to 13.5% of each week's Southwestern District commercial catch. We then found it reasonable to attribute the weighted weekly average (weighted by number of fish processed) of the sampled processors' tag recovery rates to these remaining unsampled fish.

Three pooling arrangements were eventually considered. The first estimate (Pooling #1) was formed by ignoring the effects of the processors and treating the sample as a representative sample from the entire district, week-by-week. The next estimate (Pooling #2) was formed by attributing the weighted average of the mark recovery rate in the sampled processors to the unsampled processors; here, the floating processors were grouped with the unsampled processors. In the final estimate (Pooling #3), the floating processors were pooled with *Processor A*, as described above.

The results were somewhat surprising. When each weekly sample was treated as representative of the Southwestern District-wide week's catch (Pooling #1), the estimated hatchery harvest was 6.8 million fish, or 56% of the harvest. When the assumption was made (incorrectly) that this was a random sample of fish from the total catch each week, the estimated 80% confidence interval was 6.6 to 7.1 million hatchery fish in the Southwestern District. Using this somewhat flawed pooling arrangement, the coefficient of variation was calculated to be less than 3% of the estimated hatchery contribution.

When the weighted average mark recovery rate from the sampled processors was attributed to the unsampled processors, including the floating processors (Pooling #2), the estimated hatchery harvest was 54%. It seems the processors with high hatchery occurrence (primarily *Processor A*) were approximately in balance with the processors with low hatchery occurrence (*Processor D*) in the sample.

When *Processor A* was pooled with the floating processors (Pooling #3), the estimated harvest of hatchery salmon in the Southwestern District rose to 63%. This final pooling arrangement was judged to be the most reasonable, and it was adopted for further discussion.

Next we tried to assess what could be done about other troubling questions raised by the diagnostic checks on the tag rate discussed above. Recall that the examination of the observed tag rate in the brood stock was somewhat comforting for AFK and Esther Hatcheries, but extremely troubling for the Cannery Creek Hatchery. The problems with the Cannery Creek Hatchery, although annoying for the conclusions about the hatchery itself, were of relatively small consequence to the overall conclusions of the study because the contribution of this hatchery was relatively small. The expansion factors for the tagging at Cannery Creek Hatchery were estimated from the returning adults and were much larger than the expansion factors reported at the time of release. The estimate of Cannery Creek Hatchery's contribution was only about 7% of the hatchery harvest in the Southwestern district or about 4% of the total Southwestern District harvest, using the largest reasonable expansion factors. We concluded that an error of a factor of two for this hatchery would not change the conclusions about the overall effect of the hatcheries as a group.

Finally, to assess the sensitivity of the hatchery harvest estimates to uncertainty in any single one of the tagging expansion factors, each expansion factor was individually raised by 10%, and the hatchery contribution was recalculated using the final pooling arrangement. The results of this exercise are found in Table 2; the only tag code that showed any substantial sensitivity was code B from the AFK Hatchery.

Table 2. Sensitivity of the estimated proportional hatchery harvest to a 10% increase in individual expansion factors. The larger the deviation from 63% (the estimated hatchery component of the Southwestern District), the greater the sensitivity to the assumed expansion factor.

Hatchery/Tag Code Group	Sensitivity
Esther Hatchery	
Code A	63%
Code B	63%
AFK Hatchery	
Code C	64%
Code D	67%
Cannery Creek Hatchery	
Code E	63%
Code F	64%

Estimates for All of PWS

The estimated commercial catch of hatchery pink salmon was 5.5 million from the AFK Hatchery, 1.8 million from the Esther Hatchery in the Southwestern District, and making the best use of the flawed data, 0.5 million from Cannery Creek Hatchery. This meant the wild stock component of the Southwestern District catch was 4.4 million fish. To even generally comment on the exploitation rate of the hatchery salmon, some assessment of the entire production of each hatchery was needed. The hatchery production consisted of four elements:

1. harvest in the Southwest District,
2. harvest in the other districts,
3. hatchery sales harvests, and

Table 3. Tag recovery data and estimated commercial fishery contributions by hatchery and fishing district.

Fishing District	District Catch	Fish Examined Number	Fish Examined Percent	Number of Fish Missing Adipose Fin	Number of Tag Recoveries	Commercial Fishery Contribution by Hatchery: Armin F. Koernig	Hatchery: Esther	Hatchery: Cannery Creek	Hatcheries Combined Number	Hatcheries Combined Percent
Eastern District Pink Salmon Tag Recovery										
District Total	6,964,531	324,129	4.7	97	19	24,636	14,156	17,185	55,977	0.8
Northern District Pink Salmon Tag Recovery										
District Total	2,226,049	214,971	9.7	349	199	11,445	177,991	1,061,234	1,250,670	56.2
Coghill District Pink Salmon Tag Recovery										
District Total	1,784,086	103,548	5.8	123	86	12,868	407,606	233,513	653,978	36.7
Northwest District Pink Salmon Tag Recovery										
District Total	540,455	35,462	6.6	18	10	16,151	58,077	0	74,228	13.7
Southwest District Pink Salmon Tag Recovery										
District Total	13,333,581	1,137,357	8.5	2,036	1,601	5,910,639	1,771,233	469,852	8,151,724	61.1
Southeast District Pink Salmon Tag Recovery										
District Total	955,988	132,581	13.9	63	2	10,480	0	0	10,480	1.1
Season Total	25,804,690	1,948,048	7.5	2686	1917	5,986,219	2,429,062	1,781,784	10,197,065	39.5%

4. those fish that escaped these fisheries and returned to the hatcheries for use as brood stock.

Coded-wire tag expansions were generated for six other fishing districts in PWS without consideration of processors as a feature of the recovery stratification (Table 3). In some tag recovery strata, no recovery took place, and values that were considered reasonable by fisheries managers were used to stand for missing data. Without these imputed values, estimates of total PWS harvests would not be possible. Furthermore, these imputed values were negligible in terms of the overall estimate of PWS hatchery contribution. To be specific, approximately 80% of the total commercial catch of hatchery fish were caught in the Southwestern District by the analysis described above, while approximately 87% of the AFK and the Esther Hatchery returns were taken in this district. The addition of estimates of hatchery contribution outside the Southwestern District resulted in an estimated contribution to PWS commercial fisheries of 5.99 million fish from the AFK Hatchery and 2.43 million fish from the Esther Hatchery; after consideration of the problems with the analysis of the Cannery Creek Hatchery estimates, the contribution from this hatchery was assumed to be 1.78 million fish (Table 4). The contribution from the Solomon Gulch Hatchery in Valdez, not included in this study, was assumed to be 3.5 million fish (Valdez Fisheries Development Association; personnel communication). The total harvest of pink salmon in PWS was estimated to be 26.1 million fish in 1987, so the estimated hatchery contribution to the entire commercial fishery was 52%. The estimated total interceptions in the commercial fishery of the AFK and the Esther Hatchery fish were 78% and 80%, respectively. This is a reasonable estimate of the harvest rate that at least some wild stocks experienced in PWS during 1987. Additional detailed estimates of hatchery performance in PWS can be found in Appendices A and B.

Table 4. Prince William Sound hatchery return summary for 1987.

Hatchery	Commercial Catch	Hatchery Sales	Escapement	Total	% Interception	Fry Release	Marine Surv.
Armin F. Koernig	5,986,219	1,237,332	390,000	7,613,551	78.6	112,527,515	6.8
Esther	2,429,062	303,381	300,000	3,032,443	80.1	34,437,214	8.8
Cannery Creek	1,781,784	41,002	300,000	2,122,786	83.9	56,200,000	3.8
Solomon Gulch[a]	4,000,000	1,106,153	300,000	5,406,153	74.0	54,670,000	9.9
Main Bay[a]	328,000	0	0	328,000	100.0	32,729,000	1.0
Totals	14,525,065	2,687,868	1,290,000	18,502,933	78.5	290,563,729	6.4

[a] Imputed values from assumptions about hatchery performance.

CONCLUSIONS

The first year of this study showed that it is practical to use half-length, coded-wire tags to study hatchery contribution to a large mixed stock pink salmon fishery with a large hatchery component. Extremely low tag rates were used in this study. Although the estimates of sampling error were flawed, the coefficient of variation for the hatchery component of catch for the Southwestern District, where over 80% of the hatchery fish were harvested, was extemely small. This indicates that the resources devoted to this study were adequate to estimate the hatchery component in this district.

RECOMMENDATIONS

The 1987 study provided several lessons. In future years, processors will need to be incorporated into the structure of the recovery. Better quality assurance is needed at the time of tagging, but for the most part, this can only come with some familiarity with the technology. Because this technology is new to this application, it is hard to tell what resolution may eventually be possible. Managers would like answers to very specific questions about hatchery fish occurrence that may eventually be answerable by improving the recovery system and, possibly, by introducing test fishing for marked fish.

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Appendix A. Season summary of the 1987 Prince William Sound coded-wire tag recovery program by fishing period and district.

						Commercial Fishery Contribution to				
				Number of		Hatchery				
Fishing Period	District Catch	Fish Examined Number	Fish Examined Percent	Fish Missing Adipose Fin	Tag Recoveries	Armin F. Koernig	Esther	Cannery Creek	Total Hatchery Contribution Number	Total Hatchery Contribution Percent
Eastern District Pink Salmon Tag Recovery Program										
6/26	1,103,179	1,211	0.1%							
6/29-7/3	2,069,933									
7/8-9	1,243,059	27,138	2.2%	4	0	0	0	0	0	0.0%
7/14-16	498,524	80,609	16.2%	22	0	0	0	0	0	0.0%
7/21-23	408,673	22,592	5.5%	6	0	0	0	0	0	0.0%
7/28-30	516,131	62,069	12.0%	19	2	0	1,896	4,669	6,565	1.3%
8/4-7	No fishery									
8/10-14	773,830	77,824	10.1%	20	6	9,526	5,369	8,879	23,774	3.1%
8/17-21	288,132	45,156	15.7%	26	11	15,110	6,891	3,637	25,638	8.9%
8/24-28	58,275	7,530	12.9%	0	0	0	0	0	0	0.0%
8/31-9/4	4,795									
District Total	6,964,531	324,129	4.7%	97	19	24,636	14,156	17,185	55,977	0.8%
Northern District Pink Salmon Tag Recovery Program										
6/29-7/3	135,362									
7/8-9	73,077	1,046	1.4%			0	0	0	0	0.0%
7/14-16	200,298	30,818	15.3%	11	1	0	0	3,726	3,726	1.9%
7/21-23	178,123	32,500	17.7%	14	6	0	1,017	17,924	18,941	10.6%
7/28-30	356,483	30,152	8.4%	67	34	0	12,913	256,479	269,392	75.6%
8/4-7	257,930	26,564	8.6%	68	33	5,570	12,558	232,410	250,538	97.1%
8/10-14	381,428	46,682	11.0%	74	56	0	73,736	91,000	164,826	43.2%
8/17-21	496,956	47,209	8.2%	115	69	5,875	77,767	359,605	443,247	89.2%
8/24-28	146,392					0	0	100,000[2]	100,000	68.3%
District Total	2,226,049	214,971	9.7%	349	199	11,445	177,991	1,061,234	1,250,670	56.2%
Coghill District Pink Salmon Tag Recovery Program										
6/15-7/16	427,243	32,131	7.1%	8	0	0	0	0	0	0.0%
7/21-23	159,327	20,666	13.7%	6	0	0	0	0	0	0.0%
7/28-30	156,946	9,589	5.9%	7	5	0	14,731	0	14,731	9.4%
8/4-7	367,4091[1]	27,354	5.9%	71	53	12,868	101,677	126,580	241,125	65.6%
8/10-14	370,755[1]	13,808	3.7%	31	28	0	126,198	71,933	198,131	53.4%
8/17-21	221,768					0	100,000[2]	35,000[2]	135,000	60.9%
8/24-28	34,388					0	25,000[2]	0	25,000	72.7%
8/31-9/4	46,250					0	40,000[2]	0	40,000	86.5%
District Total	1,748,086	103,548	5.8%	123	86	12,868	407,606	233,513	653,987	36.7%

-Continued-

Appendix A. (page 2 of 2)

Northwest District Pink Salmon Tag Recovery Program										
7/14-16	149,319	5,291	3.6%	2	0	0	0	0	0	0.0%
7/21-23	128,221	8,004	6.2%	2	1	0	2,884	0	2,884	2.2%
7/28-30	149,490	22,167	14.8%	14	9	16,151	5,193	0	21,344	14.3%
8/4-7		Combined with Coghill District								
8/10-14		Combined with Coghill District								
8/17-21	37,960					0	20,000[2]	0	20,000	52.7%
8/24-28	63,563					0	30,000[2]	0	30,000	47.2%
8/31-9/4	11,902								0	0.0%
District Total	540,455	35,462	6.6%	18	10	16,151	58,077	0	74,228	13.7%
SW District Pink Salmon Tag Recovery Program										
7/21-23	729,724	48,920	6.7%	24	14	67,677	14,917	0	82,594	11.3%
7/28-30	1,290,800	127,433	9.9%	243	176	558,763	117,321	99,381	775,465	60.1%
8/4-7	3,270,861	336,927	10.3%	618	465	1,404,145	467,123	157,460	2,028,728	62.0%
8/10-14	3,885,502	297,867	7.7%	591	474	1,861,858	595,476	109,194	2,566,528	66.1%
8/17-21	2,748,034	252,887	9.2%	429	357	1,059,399	390,851	97,226	1,547,476	56.3%
8/24-28	1,092,250	73,323	6.7%	131	115	688,797	185,545	6,591	880,933	80.7%
8/31-9/4	316,410					270,000[2]	0	0	270,000	85.3%
District Total	13,333,581	1,137,357	8.5%	2,036	1,601	5,910,639	1,771,233	469,852	8,151,724	61.1%
Southeast District Pink Salmon Tag Recovery Program										
7/14-16	154,218	10,218	6.6%	3	0	0	0	0	0	0.0%
7/21-23	374,987	64,489	17.2%	26	0				0	0.0%
7/28-30	356,391	55,023	16.9%	33	1	3,103	0	0	3,103	0.9%
8/4-7		No fishery								
8/10-14		No fishery								
8/17-21	29,834	2,851	9.6%	1	1	7,377	0	0	7,377	24.7%
8/24-28	40,558									
District Total	955,988	132,581	13.9%	63	2	10,480	0	0	10,480	1.1%
Season Total	25,804,690	1,948,048	7.5%	2,686	1,917	5,986,219	2,429,062	1,781,784	10,197,065	39.5%

[1] Combined with Northwest District

[2] No tag recovery data available. Estimates were provided by fishery manager guesses and proximity to the hatchery.

Appendix B. Estimated catch of pink salmon returning to Armin F. Koernig, Cannery Creek, and Esther Hatcheries in 1987 by week and fishing district.

	Fishing District													
	Eastern		Northern		Coghill		Northwest		Southwest		Southeast			
Fishing Period	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Weekly Total	District Total
Armin F. Koernig Hatchery:														
July 8-9	0	0.0%	0	0.0%									0	0.0%
July 14-16	0	0.0%	0	0.0%	0	0.0%	0	0.0%			0	0.0%	0	0.0%
July 21-23	0	0.0%	0	0.0%	0	0.0%	0	0.0%	67,677	100.0%			67,677	1.1%
July 28-30	0	0.0%	0	0.0%	0	0.0%	16,151	2.8%	558,763	96.7%	3,103	0.5%	578,017	9.7%
Aug 4-7			5,570	0.4%	12,868	0.9%	a/		1,404,145	98.7%			1,422,583	23.8%
Aug 10-14	9,526	0.5%	0	0.0%	0	0.0%	a/		1,861,858	99.5%			1,871,384	31.3%
Aug 17-21	15,110	1.4%	5,875	0.5%					1,059,399	97.4%	7,377	0.7%	1,087,761	18.2%
Aug 24-28	0	0.0%							688,797	100.0%			688,797	11.5%
Aug 31-Sep 4									270,000	100.0%			270,000	4.5%
District Total	24,636	0.4%	11,445	0.2%	12,868	0.2%	16,151	0.3%	5,910,639	98.7%	10,480	0.2%	5,986,219	100.0%
Cannery Creek Hatchery:														
July 8-9	0	0.0%	0	0.0%									0	0.0%
July 14-16	0	0.0%	3,726	100.0%	0	0.0%	0	0.0%			0	0.0%	3,726	0.2%
July 21-23	0	0.0%	17,925	100.0%	0	0.0%	0	0.0%	0	0.0%			17,924	1.0%
July 28-30	4,669	1.3%	256,479	71.1%	0	0.0%	0	0.0%	99,381	27.6%	0	0.0%	360,529	20.2%
Aug 4-7	0	0.0%	232,410	45.0%	126,580	24.5%	a/		157,460	30.5%			516,450	29.0%
Aug 10-14	8,879	3.2%	91,090	32.4%	71,933	25.6%	a/		109,194	38.8%			281,097	15.8%
Aug 17-21	3,637	0.7%	359,605	72.6%	35,000	7.1%			97,226	19.6%	0	0.0%	495,468	27.8%
Aug 24-28	0	0.0%	100,000	93.8%					6,591	6.2%			106,591	6.0%
Aug 31-Sep 4													0	0.0%
District Total	17,185	1.0%	1,061,234	59.6%	233,513	13.1%	0	0.0%	469,852	26.4%	0	0.0%	1,781,784	100.0%
Esther Hatchery:														
July 8-9	0	0.0%	0	0.0%									0	0.0%
July 14-16	0	0.0%	0	0.0%	0	0.0%	0	0.0%			0	0.0%	0	0.0%
July 21-23	0	0.0%	1,017	5.4%	0	0.0%	2,884	15.3%	14,917	79.3%			18,818	0.0%
July 28-30	1,896	1.2%	12,913	8.5%	14,731	9.7%	5,193	3.4%	117,321	77.2%	0	0.0%	152,054	6.3%
Aug 4-7			12,558	0.0%	101,677	0.0%	a/		467,123	0.0%			0	0.0%
Aug 10-14	5,369	0.7%	73,736	9.2%	126,198	15.8%	a/		595,476	74.4%			800,779	33.0%
Aug 17-21	6,891	0.0%	77,767	0.0%	100,000	0.0%	20,000	0.0%	390,851	0.0%	0	0.0%	0	0.0%
Aug 24-28	0	0.0%	0	0.0%	25,000	0.0%	30,000	0.0%	185,545	0.0%			0	0.0%
Aug 31-Sep 4					40,000	0.0%							0	0.0%
Season Total	14,156	0.6%	177,991	7.3%	407,606	16.8%	58,077	2.4%	1,771,233	72.9%	0	0.0%	2,429,063	100.0%

[a] Data combined with Coghill District data.

The 1988 Tag Study of Pink Salmon From The Solomon Gulch Hatchery In Prince William Sound, Alaska

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ABSTRACT

In 1987, 178 thousand pink salmon (*Oncorhynchus gorbuscha*) fry from the Solomon Gulch Hatchery, in Prince William Sound, Alaska, were marked by the removal of the adipose fin and injected with a half-length, coded-wire tag. These fish were mixed with untagged cohorts, and released in four release groups totaling 60 million pink salmon fry. In 1988 the wild stocks experienced a catastrophic run failure, resulting in a severe disruption of the fishery and partial disruption of the tagging study. In spite of several difficulties, we concluded the contribution of the Solomon Gulch Hatchery to the 1988 commercial pink salmon fishery in Prince William Sound to be approximately 300 thousand fish, with an approximate ex-vessel value of $870,000. We also concluded there was a critical "tag-loss bias." Without correction, we estimated this bias would have caused the initial estimate to be over 50% too low. This bias was observed by comparing the tag rate at release with the observed tag rate in the brood fish returning to the hatchery. Most likely this resulted from differential mortality of tagged fish, tag loss, or both. For future coded-wire tagging studies, we recommend more similar rearing times for untagged and tagged fish within each release group, similar tag rates between groups, deeper tag placement, and better documentation of release and tagging procedures.

INTRODUCTION

Four large hatcheries produce pink salmon (*Oncorhynchus gorbuscha*) in Prince William Sound (Figure 1 in *Paper #1*). In 1986 a pilot study was undertaken to test the feasibility of coded-wire tagging hatchery pink salmon in Prince William Sound (PWS). Three hatcheries participated in the original study: the Armin F. Koerning Hatchery, Esther Hatchery, and Cannery Creek Hatchery. Tags were recovered in 1987, and the results were summarized in two reports: a description of the tagging technique was supplied by Peltz and Miller (*in press*); tagging results and conclusions were described by Peltz and Geiger (*Paper #1*). At the conclusion of the first pilot study, the technique of coded-wire tagging pink salmon in the fry stage with half-length tags was found to be workable with some reservations.

The Solomon Gulch Hatchery, operated by the Valdez Fisheries Development Association (VFDA), was the only large pink salmon producer which did not tag pink salmon fry releases in 1986. In 1987 approximately 178,000 pink salmon were tagged with half-length, coded-wire tags out of 60 million pink salmon fry released from the VFDA Hatchery at Solomon Gulch.

The goals of this second study were to provide a post-season analysis of the temporal and spatial contribution of the hatchery to the intercepting commercial PWS fisheries and to discover and correct problems in providing this estimate. The hatchery operators also wished to test the survival of fish in four separate release groups, each of which was tagged with unique tag codes representing a different cultural practice (this VFDA objective was not included in the analyses we conducted).

MATERIALS AND METHODS

Tag Application

In 1987 fry at the Solomon Gulch Hatchery were moved from the incubators to saltwater rearing pens in four separate groups of approximately equal size. Because each group was released from the incubators on different dates and experienced different rearing conditions, a portion of each group was tagged with a coded-wire tag engraved with a group tag code unique to that group. Three of the four release groups were actually represented by more than one tag code, but the different codes within a group did not represent any functional differences in release timing or rearing conditions.

The transfer of fry from incubators for the four release groups began on 3, 13, 16, and 18 March, respectively, and each took 2 d to complete (Table 1). While the nonvolitional release of each group of fry took only 2 d, the time required to tag fry in each group ranged from 6-12 d. For this reason the mean date of transfer of tagged fish to net pens lagged behind the mean transfer date for untagged fish in the same group. Rearing times for tagged fish in each of the four groups were correspondingly shorter than for untagged fish, and the tagged fish in each group were also smaller than untagged fish at the time of release from the net pens (Table 1).

All unmarked fish were transferred nonvolitionally from the incubators to rearing pens. For each release group the transfer took only 2 d. The first group was moved from the incubators to a freshwater raceway, held and fed in the raceway for 8 d, then moved to a saltwater net pen (pen 1) where they were held and fed. The remaining three groups were all moved directly from the incubators to separate saltwater net pens (pens 2, 3, and 4) where they were held and fed for varying lengths of time. Automated fry counters normally used to enumerate the unmarked portion of a fry release were swamped by the huge, short-term, nonvolitional releases and could not be relied upon. Fry transfers for each group were estimated from egg inventories and the estimated egg to fry mortality rates in the incubators for each group.

Two crews tagged portions of each release group. Each crew consisted of one tagger and two clippers. Tagging operations worked 6 d/week for one 8 h shift each day. Tagging crews followed tag application methods outlined by Miller (1986).

Table 1. Comparison of mean dates of transfer from incubators to saltwater net pens, mean dates of release from net pens, duration of saltwater rearing, and size at time of release for untagged versus tagged fry from each of the four release groups released from the Solomon Gulch hatchery in 1987.

Statistic	Release Groups			
	Pen 1	Pen 2	Pen 3	Pen 4
Mean Date of Transfer to Net Pens - Untagged	13 Mar	14 Mar	16 Mar	18 Mar
Mean Date of Transfer to Net Pens - Tagged	21 Mar	26 Mar	11 Apr	2 Apr
Date of Release From Net Pens - All Fry	1 May	10 May	6 May	10 May
Mean Number of Saltwater Rearing Days - Untagged	49	58	51	53
Mean Number of Saltwater Rearing Days - Tagged	41	45	25	38
Rearing Time Difference (Untagged Minus Tagged)	8	13	26	15
Mean Size (in grams) at Release - Untagged	0.386	0.474	0.376	0.470
Estimated Size (in grams) at Release - Tagged	0.386	0.420	0.290	0.340

Fish to be tagged were emptied from the incubators into a holding tank in the tagging room. Fry from the holding tank were anesthetized in a cooled, aerated, and buffered MS-222 solution. When anesthetized, fry were adipose-clipped, tagged, and then placed in a bucket of aerated water until they recovered from the aesthesia and initial tagging trauma; they were then transferred to another holding tank. All fish tagged during the course of one day were held overnight in this tank, and mortalities were totaled the following morning. A sample of 100 fry from the holding tank were run through a magnetizer and tag detection tube assembly to check for tag loss; a subset of these same fish were also examined for consistency and accuracy of tag placement. Fish processed by each fin clipper were also sampled to assess fin clip quality and consistency. Fish in the holding tank were then transferred to the net pen to rejoin the rest of the release group they represented. Within each rearing pen however the tagged portion was held in a smaller pen, segregated from the untagged portion. Hatchery personnel in SCUBA gear performed daily underwater inspections of each rearing pen and the short-term mortalities among the tagged fish in each pen were enumerated. On the day of release from the net pens, tagged fish were sampled again to test for short-term tag loss. The rate of tag loss for the subsample was used to estimate the short-term tag loss for all the tagged fish in the pen. Ignoring the distinction between estimated and known quantities, the total number of fish from each of the four net pens which were released and had valid tags was then calculated as follows:

$$T_{vt}=(T_t - M_{ot} - M_{st}) - (T_t - M_{ot} - M_{st})L_{st}$$

where:

T_{vt}= the total number of fish with valid tags in group t at the time of release;

T_t= the total number of fish tagged from treatment group t;

M_{ot}= the overnight mortality count of tagged fish from treatment group t;

M_{st}= the short term mortality count of tagged fish from treatment group t during rearing; and

L_{st}= the proportion of a sample from tagged fish in treatment group t which lost tags during saltwater rearing.

Because of the rapid, nonvolitional nature of the fry release in 1987, even at peak speed tagging operations could not keep pace with releases of unmarked fish. The transfer of tagged fish to saltwater rearing pens frequently lagged several days behind the transfer of unmarked fish in the same group. This caused great disparities in the rearing times of untagged fish and tagged fish in the same release group. Tagging operations for release group #2 were truncated when additional samples of fish to tag did not arrive on time, and the final tagged to untagged ratio for that group was considerably smaller than for the other three groups. These disparities in the rearing times of untagged fish and tagged fish were in violation of the basic tag application rules outlined in Miller (1986).

Fry traps were used to capture 200 to 300 untagged fish from each pen for daily average size data during saltwater rearing. Growth curves were constructed for each rearing group of untagged fish based on daily average weights for each group and saltwater degree-day data at the net pen site. Tagged fry were sampled for average weight at the time of tagging and when transferred to net pens. They were not sampled during rearing. Daily growth during rearing and average size at release for tagged fish in each treatment group were extrapolated using temperature based growth models and data from untagged fry in each group.

Tag Recovery

Commercial catches of pink salmon were sampled at eight of the twelve facilities which processed pink salmon in Prince William Sound in 1988. Harvests of pink salmon used for hatchery revenue, called *cost recovery harvests*, and hatchery brood stock were also sampled. The proposed sampling plan for tags in the fishery was based on stratified random sampling, assuming that fish entering the processing channels at sampled processors could be considered an approximately random sample of all fish caught in each specific sampling structure. Based on the 1987 coded-wire tag study in the sound (*Paper #1*), the fishery was stratified into weeks, processors, and fishing districts. Later, fishing districts were pooled to increase the number of recoveries by including catches that could not be attributed to a single fishing district. Later still the processors were pooled to examine the effect of this action. The sampling supervisor maintained contact with the processing plant management; when deliveries of pink salmon were expected at the selected processors, samplers were sent to the processing plants. Samplers examined fish passing through the processing lines looking for fish missing the adipose fin. Fish selected for the sample were examined for an adipose fin both visually and tactually. The selected fish were assumed to be an approximately random sample of all fish in the recovery stratum.

For each fishing boat or tender load of fish scanned, the following data were recorded: sample source (i.e., commercial catch, escapement, or cost recovery), port of delivery, name of sampler, date fish were sold or caught, date sampled, fishing gear type, name of processing facility, boat name, area of capture (subdistrict, district, or combination of districts), and number of fish examined and clips observed by species. Each fish that was found to be missing its adipose fin was pulled from the line, and its head was removed. All heads and corresponding sampling data were sent to the Coded-Wire Tag Laboratory in Juneau where tags were removed and decoded. Tag-code data together with the corresponding sampling data were entered on a centralized computer data base. Catch by processor, by district, and by fishing period were extracted from a receipt of sale (fish ticket) required by state law for all fish sold to the processors.

The Contribution Estimation Methods

The proportion of the fish tagged in release group t (t=1,2,3,4) is denoted as $P(t)$. Let N_i denote the number of fish caught in fishery i (i=1,2,...,k) let s_i denote the number of fish in that the fishery sampled for marks, and let $x_i(t)$ denote the number of tags recovered with code t in fishery i. The number of fish from the release group t that were caught in the commercial fishery, $C(t)$, is estimated as follows:

$$\hat{C}(t) = \sum_i x_i(t)\,(N_i/s_i)\,P(t)^{-1}$$

Clark and Bernard (1986) describe a theory for the estimation of confidence intervals for $C(t)$ using a large sample approximation to the Gaussian (normal) distribution. Using the method of moments, they recommend an estimator for the variance of the estimate of $C(t)$, including terms covariance for multiple tag codes. Using the approximation suggested by Geiger (1988) and ignoring negligible covariance terms, we used the following variance estimator:

$$\hat{v}(\hat{C}(t)) = \sum_i x_i(t)\,[(N_i/s_i)\,P(t)^{-1}]^2 \cdot \left\{1 - [(N_i/s_i)\,P(t)^{-1}]^{-1}\right\}.$$

The assumptions necessary to estimate $C(t)$ and the associated confidence intervals are as follows:

1. the numbers of tagged and untagged fish are known exactly;
2. the tagged sample of the original hatchery release group is a simple random sample;
3. the tags do not affect the fish with respect to the items under study (survival, timing, homing, etc.);
4. none of the marks are lost;
5. the number of fish in the fishery and the number of fish in the fishery sample are known exactly;
6. the sample of the fishery is a simple random sample (i.e., every fish in the collection off fish under consideration has an

exactly equal probability of selection independent of every other fish in the sample);

7. all marks are observed and all tags decoded.

RESULTS AND DISCUSSION

The 1987 release of pink salmon from the Solomon Gulch hatchery totaled 60 million fish. Unmarked releases in release groups #1 to #4 totaled 13.2 million, 15.0 million, 14.5 million, and 16.9 million, respectively (Table 2). The tagged fish in release groups #1 to #4 numbered 40,526, 9,931, 45,558, and 82,448 fish, respectively. The tag expansion factors for release groups #1 and #3 (326 and 319, respectively) were very similar. The expansion factor for release group #4 was somewhat smaller at 205. The expansion factor of 1,507 for release group #2 was more than four times

Table 2. Number of untagged and tagged pink salmon fry from each of four release groups released from the Solomon Gulch Hatchery in 1987. For each group of tagged fish the number of overnight mortalities, the number of short-term mortalities, the percent short term tag retention and the estimated final number of valid tags released are shown. Also shown are the estimated tag rates at release for each group and the tag expansion factor at release (inverse of tag rate) for each of the release groups.

Statistic	Release Groups			
	Pen 1	Pen 2	Pen 3	Pen 4
Total Untagged From Incubators (in millions)	13.5	15.0	14.5	16.9
Total Tagged From Incubators	43,947	11,498	46,949	86,001
Overnight Mortalities	1,173	73	166	190
Short Term Mortalities	1,337	1,434	858	2,782
Short Term Retention (%)	97.8	99.4	99.2	99.3
Total Valid Tags Released	40,526	9,931	45,558	82,448
Tag Rate at Release	0.00307	0.00066	0.00314	0.00487
Tag Expansion at Release	326	1,507	319	205

as large as for any of the other groups (Table 2).

Tag Recovery Analysis

Tag Loss Bias

The analysis began by questioning whether or not the tag rate in the escapement seemed to match the reported tag rate at the time of release. For each of the four tag codes, Table 3 shows counts of the number of tags recovered in the commercial fishery, the hatchery's cost recovery fishery, and the brood stock. The distribution of four tag codes did not seem to differ among these three recovery domains (X^2=9.16, df=6, P=0.17).

The reported tag rate was 3.0 tagged fish per 1,000 pink salmon fry released from the hatchery, yet it was only 1.0 tagged fish per 1,000 adult salmon sampled from the hatchery brood stock escapement. The tag rate at release was not constant but was 3.1, 0.7, 3.1, and 4.8 fish per 1,000 for release groups #1 through #4, respectively. Thus, if release group #2 had a higher survival rate than the other groups, it would bring the aggregate tag rate down. Alternatively, this change in aggregate tag rate could signal a large tag loss or, possibly, a differential mortality of tagged fish after release. These latter two possibilities are collectively called *tag loss bias.*

Table 3. Counts of tag recoveries by release group in the brood stock, commercial catch, and hatchery cost recovery.

Statistic	Release Groups			
	Pen 1	Pen 2	Pen 3	Pen 4
Recovered in brood stock[a]	7	3	5	18
Recovered in comm. catch	22	12	8	52
Recovered in cost recovery	38	19	4	58
All adult recoveries	67	34	17	128

[a]Tags recovered in the brood year stock were found in a sample of 33,127 fish that volitionally entered the hatchery and were used for brood stock.

To assess whether or not a higher survival of the release group with the lowest tag rate could reasonably explain the drop in tag rate, the recovered tags in the brood stock was used to estimate the total (known) number of fish in the escapement. If this estimate was much lower than the actual known escapement to the hatchery, tag loss bias would be strongly suspected. The number of fish of each release group in the brood stock was estimated by multiplying the number tags from that group observed in the sample from the brood stock, by the inverse of the reported tag rate at release for the group. The estimated number of hatchery fish in the brood stock for all release groups was 12,088 fish. This was 21,000 fish less than the actual number of fish examined in the brood stock. This 64% underestimate suggested a dearth of tags in the escapement, and lent considerable credence to the hypothesis that tag loss bias accounted for a large part of the drop in the tag rate at the rack. It should be pointed out that the number of tags recovered in the brood stock was low; indeed, only three tags from release group #2 were recovered. Nevertheless, assuming that the recoveries of tags in the brood stock are generated independently under a Poisson law, an approximate 95% confidence interval based on the Gaussian approximation (e.g., Snedecor and Cochran 1967) would be 6,000-18,000 fish. The high end of this interval is still far short of the actual value of 33,127 fish examined in the brood stock.

Because the tag recovery rate in the brood stock was low, the estimates for the relative distributions of the four release groups in the brood stock and the estimate of the total hatchery contribution to the brood stock were very imprecise. To improve the precision of these estimates, the observed distribution of tag codes in the brood stock, hatchery cost recovery harvest, and commercial fishery were pooled to estimate the relative distribution of codes in the brood stock. The 246 recoveries in the pool were totaled by tag code and then scaled to total 33 (total number of tags actually recovered in the brood stock sample). When this was done, the estimated contribution of fish from all four codes to the brood stock was only 14,092 fish; still far short of the actual 33,127 fish examined in the brood stock. Therefore, either the tagged fish suffered a higher mortality after tagging than their untagged cohorts, a large number of tags were shed, a large number of external marks were lost, or a combination of all three phenomena. We concluded that a reasonable adjustment for tag loss, mortality of tagged fish, and other nonsampling errors that result in an observable distortion of the tagging rate would be found by dividing the 33,127 fish examined by the estimated number of 14,092. This provided an "adjustment factor" of 2.35. Unfortunately, this disagreement between the tag rate at release and at return could limit the strength of our conclusions.

Sampling Stratification

In 1988 the sampling effort was dispersed as widely as possible across the 12 processors that were licensed to operate in Prince William Sound. Only 4 of 12 processors were not sampled for fish processed from the commercial fishery. In all 6.3% of the commercial harvest was sampled, but 24% of the Eastern District, where most of the VFDA were assumed to have been harvested, was sampled. Fish processed by processors that were not sampled comprised 18% of the harvest in the sound.

As mention previously, Peltz and Geiger (*Paper #1*) detected distortions in the estimates of hatchery contribution caused by different rates of hatchery contributions among the processors sampled in the 1987 fishery. They concluded that processors should be included as a feature of the recovery of tags from the commercial fishery in Prince William Sound. The reason for this is that the fishing districts are large and processors may receive fish from only a small part of the district. These distortions likely reflect differences in spatial distribution of hatchery fish in the fishery and a tendency of processors to concentrate their buying in certain areas within a fishing district. Incorporating the processors as a feature of the stratification increases the complexity of the analysis. Furthermore, increasing the number of strata increases the overall sampling error (Cochran 1977).

Determining the temporal and spatial distribution of the Solomon Gulch Hatchery stock in the common property, mixed stock harvest was one of the goals of the 1988 tag recovery project. With this in mind the tag recovery effort was initially stratified by week and fishing district. Run failures of both wild and Solomon Gulch hatchery stocks resulted in low numbers of tag recoveries in the commercial harvests. Because all samples could not be attributed to a single fishing district, stratifying by fishing districts resulted in loss of sampling information. By eliminating district strata, samples from catches that could not be assigned to a single fishing district could be incorporated into the analysis and the number of usable tag recoveries, increased from 73 to 94.

In addressing the question of how to stratify, we had to answer two questions.

1. Is the gain in area-specific information worth the decrease in precision gained when fishing districts are included in the stratification?

2. Is the potential reduction in bias worth the increase in sampling error and operational complexity when the processors are included in the stratification?

The estimated contributions of the Solomon Gulch Hatchery to the sampled processors (unadjusted for tag loss bias) and the associated coefficients of variation of four stratification methods are shown in Table 4. These results appear to refute the notion that catches need to be stratified by processor in 1988. The two estimates that do not include processor as a stratification were very similar: 116,000 for district stratification (CV of 17%); and 114,000 for district and processors pooled (CV of 15%). The two estimates that include processor stratification were the most dissimilar and had the highest coefficient of variation: 99,000 for district and processor stratification(CV of 18%); and 136,000 for processor stratification (CV of 20%). These two estimates differed by nearly 40,000 fish, or about 30% of the larger estimate. Interestingly, in a single week and at a single processor, two tags were recovered in a sample that came from multiple districts.

Table 4. Estimates of Solomon Gulch Hatchery contribution to sampled processors in 1988. Estimates were generated using tagging expansion factors from release (unadjusted for tag loss bias), for the four methods of stratification: (A) week and both district and processors pooled; (B) week and fishing district with processors pooled; (C) week and processor, with fishing district pooled; and (D) week, district, and processor.

Stratification	Estimate	CV
(A) pooled	114,000	15%
(B) district	116,000	17%
(C) processor	136,000	20%
(D) district and processor	99,000	18%

These two tags expanded to over 30,000 fish and largely accounted for the differences in these two estimates and their estimates of coefficients of variation.

Table 5 lists the percentages of each processor's fish for the entire season that were of hatchery origin and the percentage for the season's commercial fishery sample that came from that processor. This distribution hints at departure from a random distribution of hatchery fish among the different processors, but this may be partly or wholly due to sampling variation. To test for departures in a random distribution of tags to each of the processors, a chi-square test of equal proportions was run on the distribution of tagged versus untagged fish in each of the sampled processors during statistical weeks 27 (June 26 - July 2), 28 (July 3 - July 9), and 29 (July 10 - July 16). These were the weeks of greatest abundance of VFDA fish in the fishery. This test provided very little evidence that the different processors were, in fact, processing

Table 5. Several statistics of interest for each of the sampled processors.

Processor[a]	Percent of processed VFDA fish[b]	CV[c]	Processor contribu- to entire sample[d]
Processor A	1.8	34	15
Processor B	4.4	35	20
Processor C	0.8	30	13
Processor D	0.3	72	10
Processor E	0.6	41	5
Processor F	6.0	48	16
Processor G	0.5	56	12
Processor H	2.0	38	10

[a] Confidentiality requirements limit the amount of processor specific information that can be released.

[b] The estimated percent of fish for the entire Commercial fishing season that were of VFDA origin.

[c] The coefficient of variation for the estimates of the number of hatchery fish processed by each respective processor.

[d] The percent of fish from the 1988 commercial fishing sample of pink salmon that came from each respective processor.

different proportions of hatchery fish (X^2=3.6, df=7, P=0.18).

Faced with this evidence, we concluded that the preferred stratification for the 1988 recoveries include weeks only. That is, the recovery was not stratified by district or by processors, and the samples from mixed districts were included for a total of 94 tags used in the analysis. Also, the increase in precision resulting from pooling districts, while not large, was still worth the loss of area-specific information.

Preferred Contribution Estimate

The preferred estimate was constructed in two stages. First, the estimated contribution of the Solomon Gulch Hatchery was calculated using the tagging rate reported at release. This was based on stratifying only by weeks; recoveries from different districts and processors were pooled. The calculated estimate was 128,000 fish. This implicitly includes estimates for the unsampled processors. The coefficient of variation for this estimate was 15%, although this by no means reflected all the uncertainty in the estimate, this coefficient of variation was based on the assumption that the tag rate was known without error; however, we saw evidence of tag loss bias. The second step was to correct, as best we could, for tag loss bias. This was done by multiplying the original estimate by the "adjustment factor" of 2.35 from the brood stock analysis. Our final estimate was then 301,000. Based on preliminary price information (Herman Savikko, Alaska Department of Fish and Game, personal communication), this catch equated to an ex-vessel value of approximately $870,000.

Effects of Fishery on Estimates

The 1988 fishing season was not typical of the kind of seasons fishery managers have come to expect in Prince William Sound: it was prosecuted almost exclusively in hatchery terminal areas. Based on the fishery's proximity to the hatcheries, the fishery managers estimated that over 90% of the total PWS pink salmon harvest originated from the four PWS pink salmon hatcheries (James Brady, Alaska Department of Fish and Game, personal communication). Yet, in 1987 when fishing occurred in all districts of the sound, the tagging studies resulted in the conclusion that slightly over half of the pink salmon harvest in the commercial fishery were of hatchery origin (*Paper #1*).

The disruption of the fishery caused by the failure of wild stocks and attendant dislocation of the fishery to terminal harvest areas, did not allow us to fully explore the most important questions we had about the coded-wire-tagged pink salmon from the VFDA hatchery at Solomon Gulch. Because historical buying patterns in the mixed stock fishery did not occur in 1988, hatchery fish distribution in the harvest was not typical of any past fishing year. Consequently, questions about the most reasonable stratification for the recovery sample were left unanswered.

RECOMMENDATIONS

To address the problem of tag toss bias, we urge stricter adherence to tagging rules for multiple releases as described by Miller (1986) and better documentation of the tagging procedures are essential in future studies. Adherence to tagging rules refers specifically to mimicking untagged releases with tagged releases, treating untagged and tagged fish within a group the same, and maintaining equal tagging rates among different groups in a release.

1. *Include processors as a stratification feature.* Because different tag recovery rates between processors were detected in 1987, when the fishery was more typical, we strongly recommend including processors as a feature of the stratification in future recovery programs in Prince William Sound.

2. *Minimize the differences in handling and processing of tagged and untagged portions of the same release group.* Tagging teams at Solomon Gulch will never be able to keep pace with, let alone mimic, the nonvolitional transfer of untagged fish from incubators to net pens unless nonvolitional transfers are slowed down or made volitional. Only then will large disparities in the dates of transfer to net pens and in the rearing times of tagged and untagged fish from the same release group be reduced or eliminated. Otherwise, differences will continue to make differential mortalities between tagged and untagged fish in a release group uncertain. Early emergence and cold water at Solomon Gulch may preclude allowing fry to outmigrate volitionally. However, slowed transfer rates and decreasing the duration of tagging for each release group by doubling the tagging crew size and tagging during two shifts will strengthen the conclusions of future tagging studies.

3. *Tag all release groups at the same rate.* The disparity in tag rates between release groups in 1987 contributed to the uncertainty in the conclusions. Release group #2, which was tagged at a rate almost five times lower than the other groups, contained fish that were physically larger at release. Larger fry at release are generally thought to experience better marine survival. If the release group which was tagged at the lower rate also had better marine survival, then the overall tag rate at the time of recovery will be small relative to the average tag rate of all groups as indicated by data at the time of release. By adjusting the release expansion factors with average brood stock recovery rates the overall hatchery contribution may be overestimated. To avoid this problem, we recommend that all release groups be tagged at nearly the same rate in future experiments.

4. Make tag placement deeper. Latent tag loss is highly suspected in light of the detected tag loss bias. Based on Miller's (1986) findings, high rates of tag loss may be due to tag placement which is too shallow. We recommend deeper tag placement in future experiments.

5. Make fish-size sampling of tagged and untagged portions of release groups as similar as possible. Sampling methods for size at release data are not included in Miller's procedures but should be standardized and well documented if size and release data are to be of any value in explaining possible sources of differential mortality between release groups and between tagged and untagged fish within groups. In 1987 it was very unclear what sample sizes were used to sample untagged fish for daily mean weight data during the saltwater rearing phase. No weight data for tagged fish were collected, and all size estimates for those fish were extrapolated from growth curves for untagged fish. We recommend examining tagged fish during rearing for average size data which are consistent with those collected for untagged fish.

6. Further investigate tag loss bias at the recovery stage of the project. In some processing plants where all fish are destined for the fresh frozen market samplers have access to district-specific samples on the processing line and can look closely at every single fish that passes in front of them. We are confident that sampling at these facilities is very accurate. However, at most of the processing facilities fish are scanned on a conveyor belt as they are pumped out of the tenders. Fish pass by the sampler at the rate of several hundred per minute. At this rate the sampler cannot possibly scan every single fish and must arbitrarily choose which fish will be subjected to visual and tactile examination for the purposes of tag recovery sampling. We have assumed that the sample of fish selected by the scanner is representative of the entire load, but this may not necessarily be the case. For the sake of speed, it is not possible for the sampler to preselect fish for sampling by some nonvisual means. Because samplers are instructed to ignore any fish for which the presence or absence of an adipose fin cannot be detected, it can be argued that fish with missing adipose fins are ignored at some rate during the visual sample selection process. In 1988 the best indication that there was little or no sampler bias during sampling off high speed conveyors was the fact that fish from the same time and area strata were frequently sampled concurrently in facilities with slower fresh-frozen processing lines and no differences could be demonstrated between the tag recovery rates for the two scanning procedures. It is difficult to design some other cost effective means of testing the sampler bias hypothesis. The surest method would be to carefully scan every fish from a load that had been previously sampled. If the process of sampling on the conveyor is unbiased then the tag recovery rate of the sampler and the tag recovery rate (adjusted for tagged fish removed by the original sampler) of the crew which scans the entire load should be approximately the same.

CONCLUSIONS

The 1987 study (Peltz and Geiger, *Paper #1*) showed that the coded-wire tag can be a workable tool for fisheries managers and hatchery operators in Prince William

Sound. This first study included all Prince William Sound hatcheries, except the one at Solomon Gulch. The study described in this paper demonstrates that the coded-wire tag tool can be made to work in the Solomon Gulch hatchery as well. This study revealed some potential problems with tag loss bias. More importantly, it also showed that with careful cooperation between data collection personnel and hatchery operators the problems can be observed and corrected.

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